Energy Storage System Modeling for Extreme Climates

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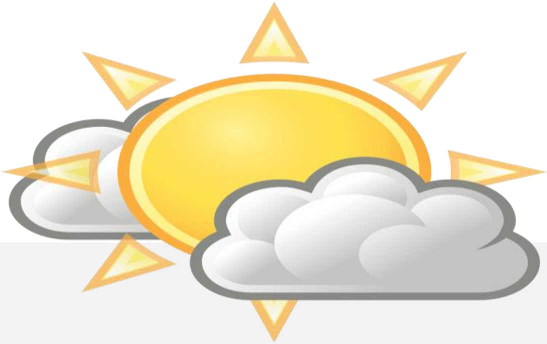
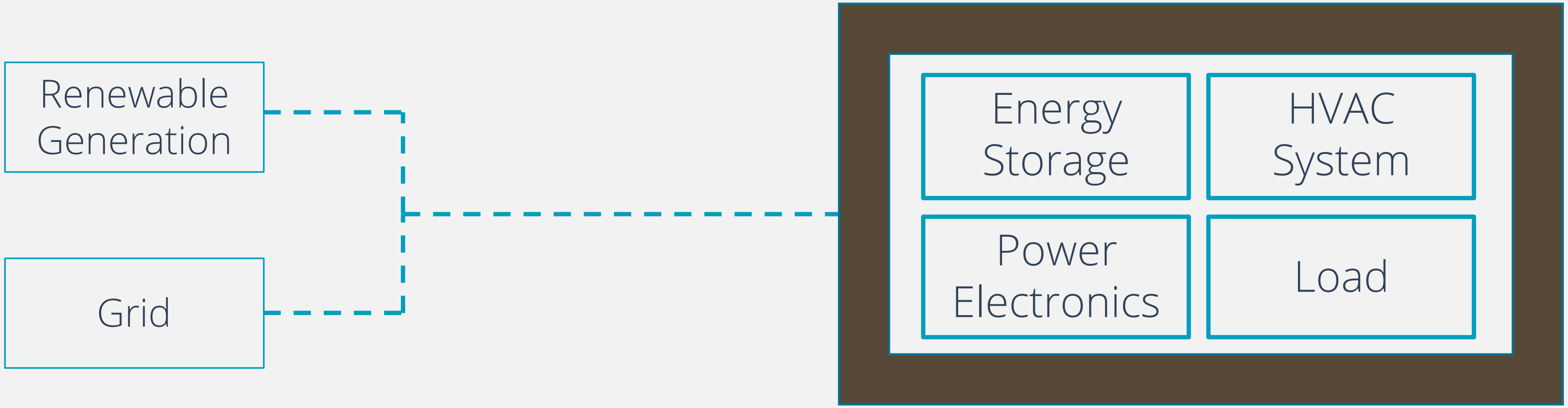
Goal



Develop modeling framework to evaluate the impact of heating/cooling on ESS technologies performance

System design - Battery inside shipping container

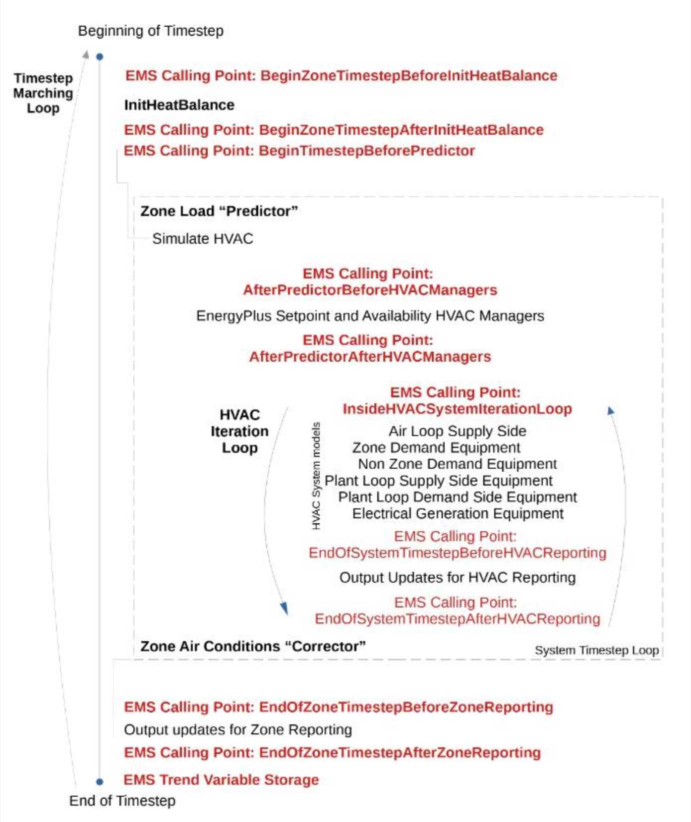
- Enclosure modeling - EnergyPlus
- Thermal models - Non-linear techno-economic model for Lion/Lead-acid batteries
- Control algorithms for thermal management/performance optimization



EnergyPlus

- Building Energy Simulation Software developed by DOE Building Technologies Office managed by NREL
- Input File (idf) describing location, building parameters, HVAC
- Weather file (.epw)
- Python API developed for simulation manipulation
- Hook into simulations at certain points with callback functions

https://energyplus.net/



Enclosure

- Shipping container with HVAC
- 40’ long, 8’ wide, 9’6” height (12.2 m, 2.4 m, 2.89 m) standard High Cube (HC) container
- Packaged Terminal Air Conditioner (PTAC)
- PTAC has heating and cooling capabilities – electric coil heater, Direct Expansion (DX) cooling coil

https://www.maloystorage.com/

https://learn.allergyandair.com/buying-ptac-units/

ESS model – Lion/Lead-acid Battery

- Non-linear model developed for techno-economic studies (Nguyen, et al, 2019)

$$S_i = n^s S_{i-1} + \tau f_i^c(p_i^c, S_{i-1}) - \tau f_i^d\left(p_i^d, S_{i-1}\right)$$

$$f_i^d = \frac{p_i^d}{n^p} + p_i^{ld}$$

$$f_i^c = n^p p_i^c + p_i^{lc}$$

$$p_i^{ld} \approx \frac{\bar{q}}{\bar{v}\bar{S}}\left[\left(r + \frac{k\bar{S}}{S_i}\right)\left(\frac{p_i^d}{n^p}\right)^2 + \frac{k\bar{S}(\bar{S}-S_i)}{S_i}\frac{p_i^d}{n^p}\right]$$

$$p_i^{lc} \approx \frac{\bar{q}}{\bar{v}\bar{S}}\left[\left(r + \frac{k\bar{S}}{(\bar{S}-S_i)}\right)(n^p p_i^c)^2 + \frac{k\bar{S}(\bar{S}-S_i)}{S_i} n^p p_i^c\right]$$

- Heat energy modeled in EnergyPlus as lost by Electric Equipment

PYOMO

- Battery control
- System Sizing for peak shaving application
- Battery cost estimated on per kW and per kWh based on data from 2019 Energy Storage Pricing Survey (Baxter, 2021)

$$\min\{c^p \bar{p} + c^q \bar{S} + C^E\}$$

$$S_i = n^s S_{i-1} + n^{rt} q_i^c - q_i^d, \forall i \in A$$

$$0 \leq q_i^c + q_i^d \leq Q, \forall i \in A$$

$$S_{min} \leq S_i \leq S_{max}, \forall i \in A$$

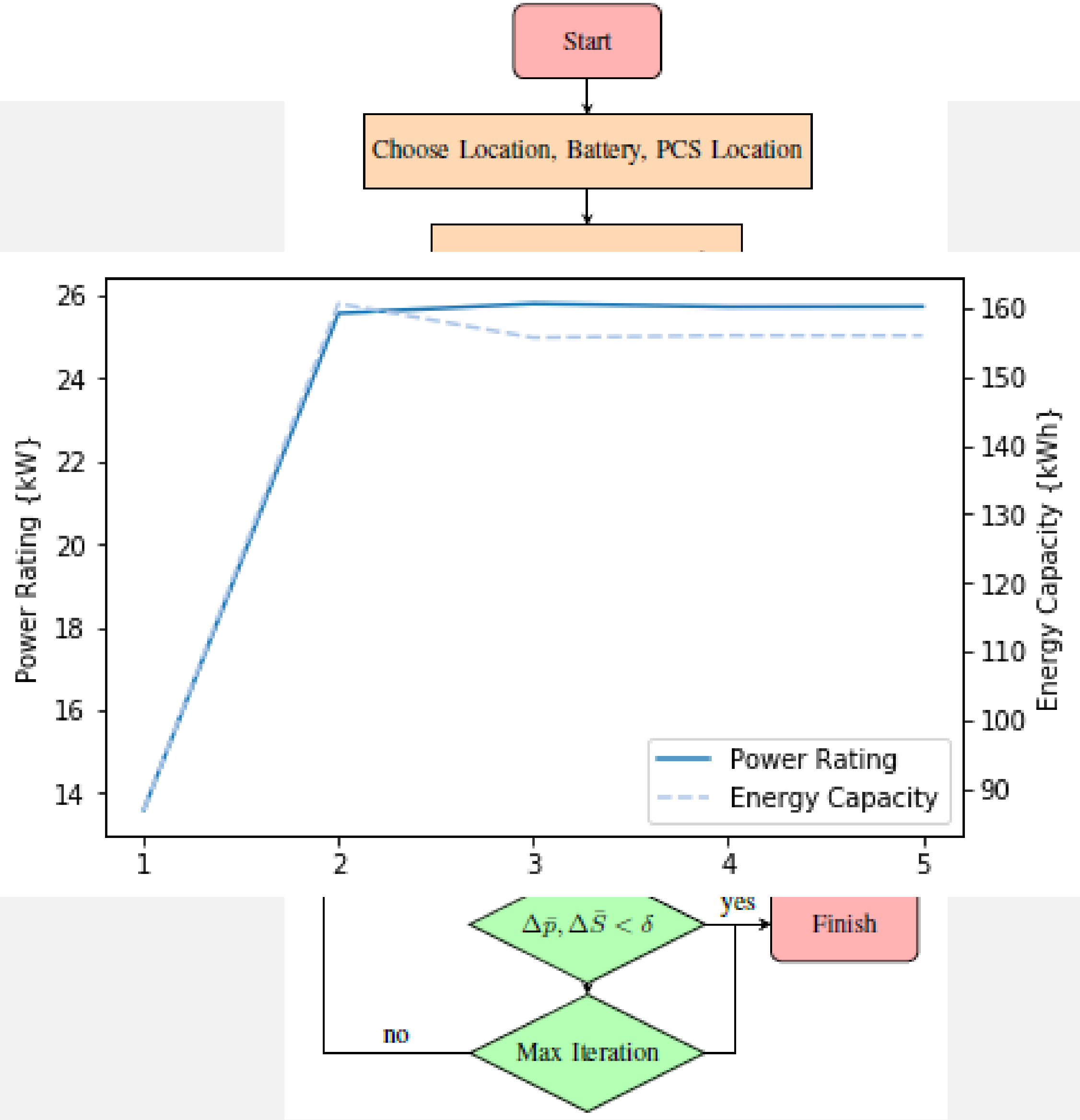
$$\sum_{i \in A} n^{rt} q_i^c - q_i^d = 0$$

$$q_i^d + q_i^{grid} - q_i^c = q_i^{load} + q_i^{hvac}, \forall i \in A$$

$$q_i^c + q_i^{grid} \leq q^{max}, \forall i \in A$$

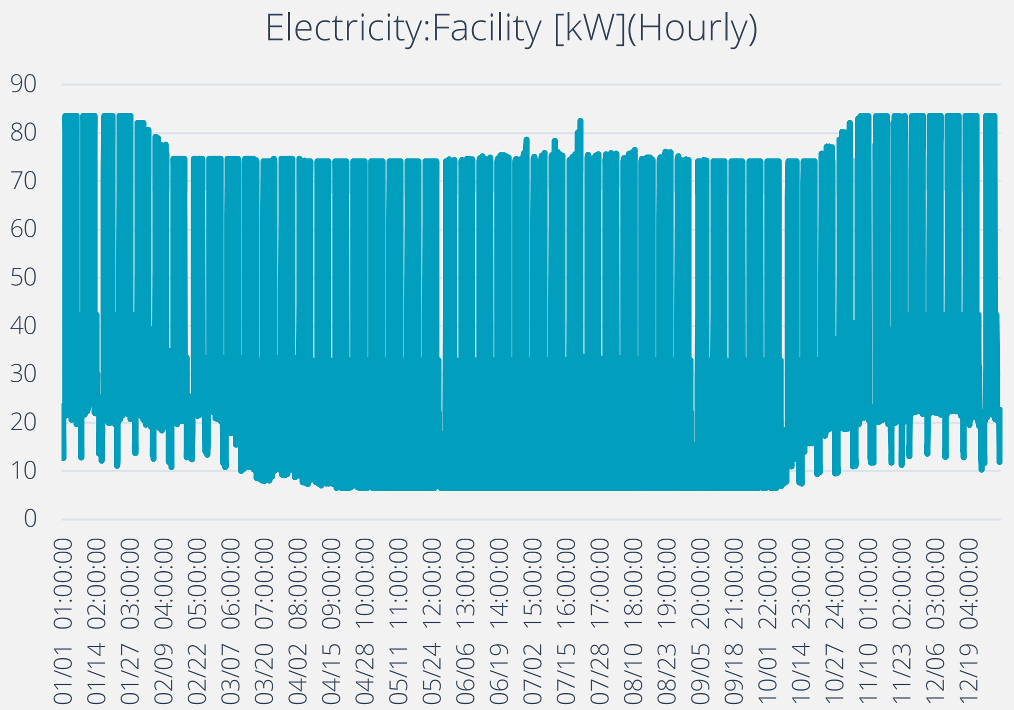
Iterative Algorithm

- Choose location, battery, PCS In or Out
- Solve base PYOMO problem without considering HVAC load
- Give charge/discharge profile from PYOMO solution to E+
- Give E+ HVAC load output to PYOMO
- Iterate above two steps until convergence or max iterations
- Nonlinear relationship -> convergence not guaranteed

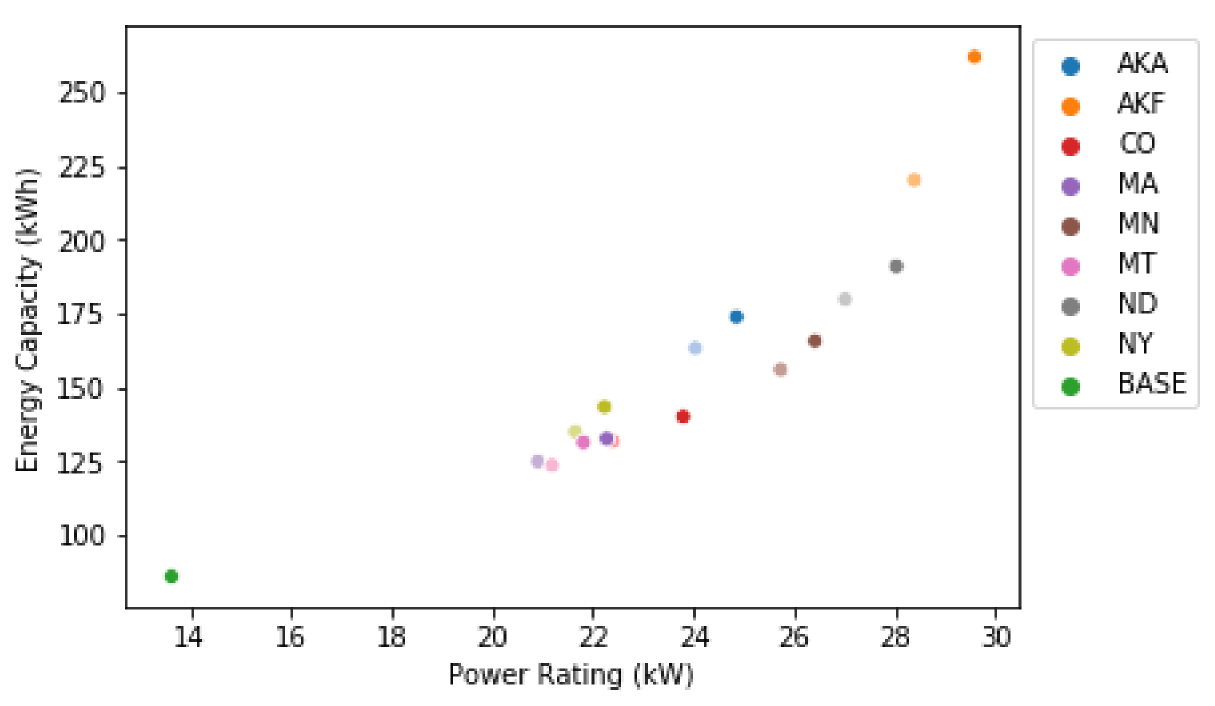


Application

- Eight locations: Fairbanks, AK; Anchorage, AK; Bismarck, ND; Minneapolis, MN; Leadville, CO; Butte, MT; Buffalo, NY; Boston, MA
- Annual simulations
- Warehouse load profile
- Demand limit 70 kW
- NMC lithium ion battery cell
- IEEE 1635 optimal operating temperature range: 15-40 °C
- Assume Battery temperature equal to enclosure temperature
- Consider PCS inside and outside the enclosure
- All locations use single rate structure



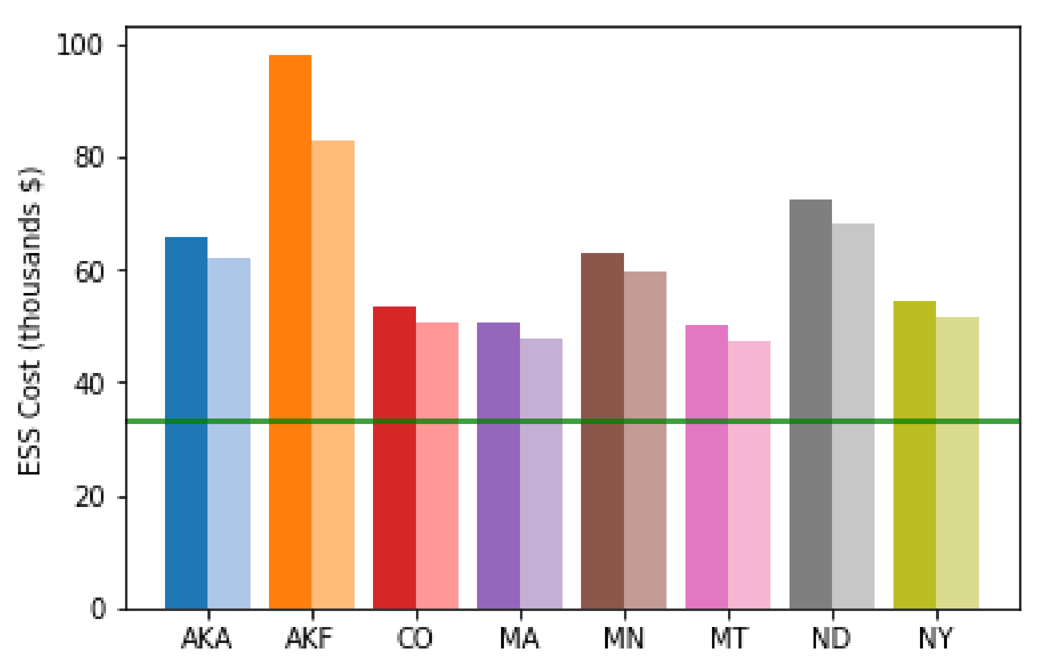
Results



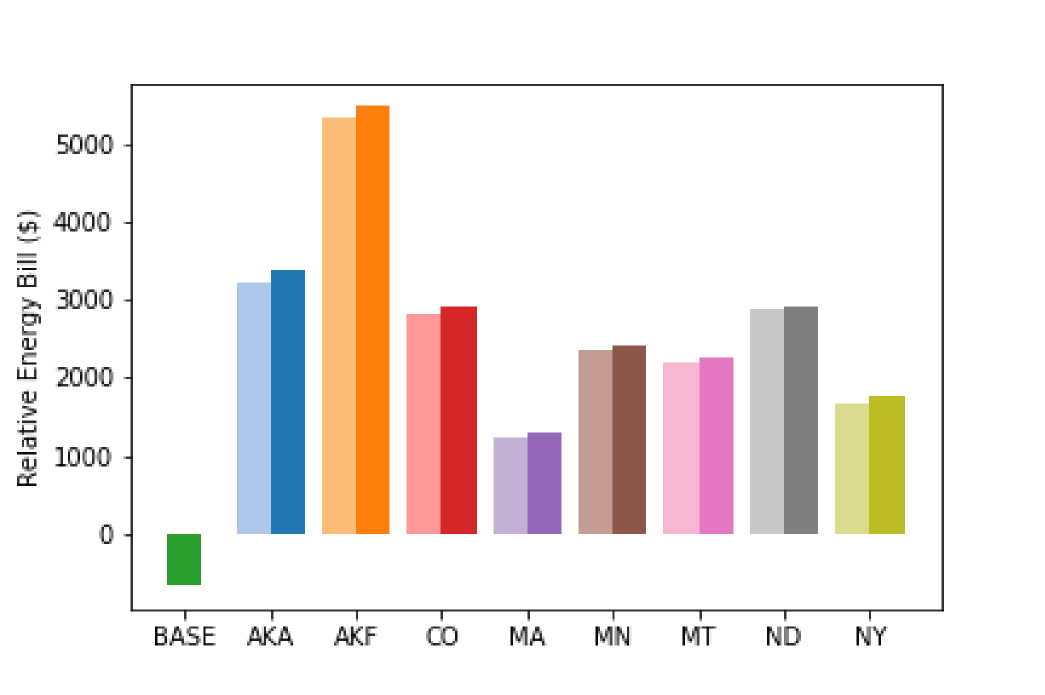
BASE Size: 13.6 kW, 86.9 kWh

Results

BESS Capital Cost

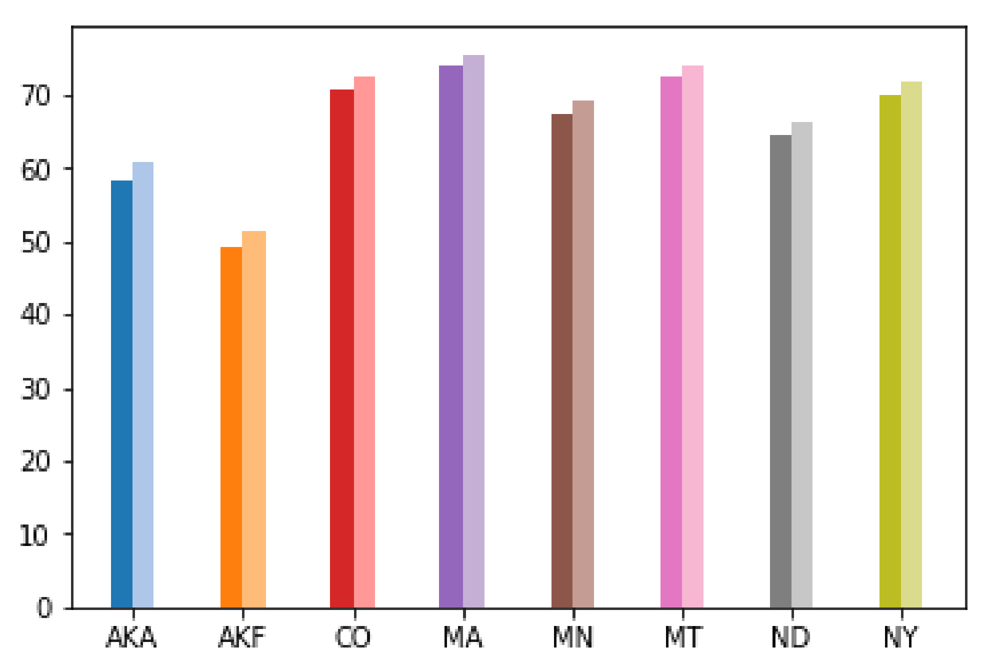


Energy Bill

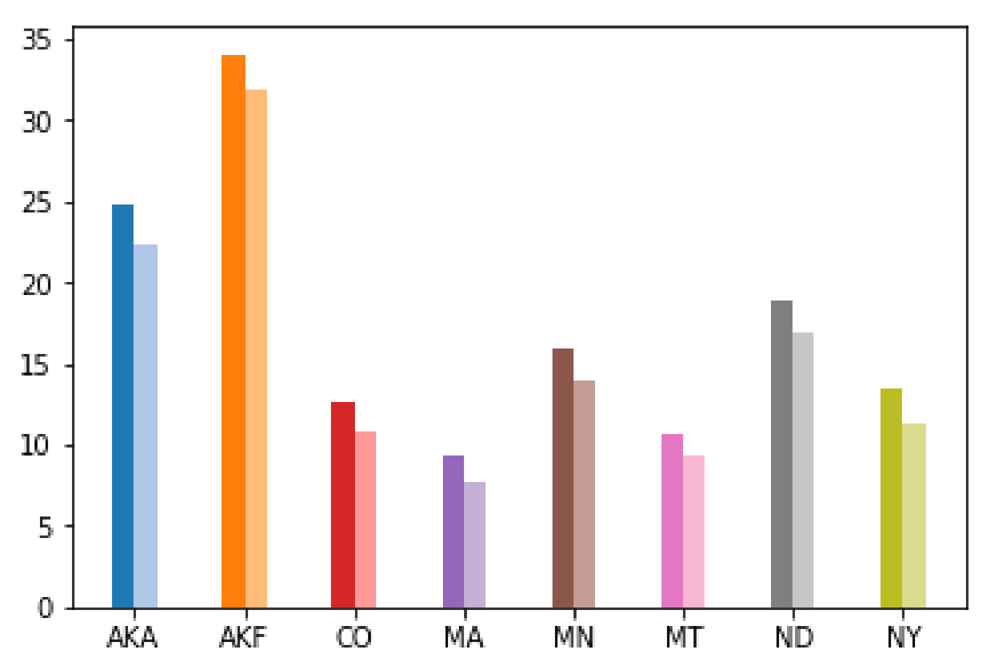


Results

% of Charge Energy to Load



% of Charge Energy to HVAC



Results

Conclusions

- Locations with extreme winters require significantly larger BESS size than anticipated without considering parasitic HVAC loads
- Placing PCS inside enclosure can reduce BESS size and costs

Future Work

- Different built enclosures, HVAC technologies, ES technologies
- Advanced thermal management/controls
- Off-grid scenario
- Extreme hot climates

Thank you.

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References

T. A. Nguyen, D. A. Copp, R. H. Byrne, and B. R. Chalamala, "Market evaluation of energy storage systems incorporating technology-specific nonlinear models," IEEE Transactions on Power Systems, vol. 34, no. 5, pp. 3706–3715, 2019.

R. Baxter, "2019 energy storage pricing survey," Sandia National Laboratories, Albuquerque, NM, Tech. Rep. SAND2021-0831, Jan 2021.

Consumption and Outdoor Temperature